Manufacturing Innovation Topics Workshop: Engineered Nanomaterials

Defense-Wide Manufacturing Science & Technology (DMS&T) Program

Name: Steve Luckowski, Abhai Kumar
Org: OSD ManTech, Crystal City
stephen.l.luckowski.civ@mail.mil
Abhai.kumar@anser.org

Agenda

- Focus Area Introduction: The State of Nanotechnology Today
  - Discussion of current applications, market sectors
  - Analysis of industry challenges and risks
  - Review of government Nano IMI planning activities to-date
- Review of Nanotechnology Processes/Ecosystem
- Economic Impact of Advancement of Nanotechnology
- The Role of an Engineered Nanomaterials Institute
- Moderated Discussion Topics

Focus Area Introduction: Why Engineered Nanomaterials?

Why does the government think Nanotechnology is a viable focus area for a National Institute for Manufacturing Innovation?

- *Pervasive:* There is a potential for Nanomaterials to impact many products and economic sectors
- *Global Market Value:* In 2006, the global market for Nano-enabled products was valued at $2.6 trillion. In 2011, the global market was valued at nearly $20.1 billion and projected to grow to $48.9B in 2017.
- *Known Technology Gaps:* Scaling from batch to continuous processing, in-process quality control and yield
- *Assumed Risk Beyond Industry:* Costly characterization/synthesis tools, equipment to scale manufacturing process, safety/health – lack of perceived ROI

GLOBAL MARKET FOR ESTABLISHED COMMERCIAL NANOPARTICLE APPLICATIONS, THROUGH 2017
($ MILLIONS)

Application	2011	2012	2017	CAGR% 2012-2017
Coatings and adhesives	1,000.0	1,040.0	2,265.3	16.8
Ultrafine polishing compounds	550.0	552.0	865.0	9.4
Refinery catalysts	170.0	176.0	214	4.0
Multilayer ceramic capacitors	131.8	161.4	528.6	26.8
Pharmaceuticals	111.0	117.3	162.2	6.7
UV sunscreens and other personal care products	90.0	100.0	450.0	35.1
Biomedical markers and detection aids	69.8	81.5	361.3	34.7
Rechargeable batteries	45	58.1	675.0	63.3
Fuel and explosive additives	30.0	30.0	30.3	0.2
Printed electronics	30.0	32.5	180.0	40.8
MRI contrast agents	11.0	11.4	13.8	3.9
Dietary supplements/nutraceuticals	5.0	5.7	10.4	12.8
Magnetic separations	5.0	6.0	14.9	20.0
Ferrofluids	1.8	2.1	4.3	15.4
Fabric treatments	1.2	1.6	5.8	29.4
Diode lasers	1.2	1.2	1.4	3.1
Proteomics arrays	<1.0	<1.0	70.0	--
Diesel fuel additives	0.7	0.8	2.7	27.5
Synthetic bone and tooth material	0.5	0.5	1.0	14.9
Surface disinfectants	0.5	0.6	1.0	10.8
Transfection reagents	0.3	0.5	3.3	45.9
Filtration systems	0.1	0.1	0.2	14.9
Photovoltaics	Neg.*	Neg.*	1.6	--
Light emitting diodes (LEDs)	Neg.*	Neg.*	100.0	--
Other	120.0	125.0	315.0	20.3
Total	2,374.9	2,504.3	6,277.1	20.2

*Negligible.

The government has established this focus area and SME team based on these assumptions. We've asked you here because we need your input.

Focus Area Introduction: Nanotechnology History (brief)

Significant investment by government and industry, but barriers to commercialization still remain:

- Federal funding of nanotechnology research, under the National Nanotechnology Initiative (NNI), more than tripled from ~$464M/year to ~$1.5B/year with total US investment in the technology reaching over $20B
- NNI characterized the 10-year period, from 2001 to 2010, as the first foundational phase and focused on inter-disciplinary research at the nano-scale
- This phase led to discoveries of new phenomena, properties and functions at the nano-scale, a library of components as building blocks for potential future applications, and improvement of existing products by incorporation of relatively simple nano-scale components and technologies
- While there's a substantial body of knowledge from this research, the size of the commercial market relative to the amount of investment is still small ($20B investment for $2B in Nanoparticle applications)

Focus Area Introduction: Review of Government Activities

The Government identified the following trends within the existing body of Nanomaterials work/research:

- The size of the commercial market, relative to the amount of commercial and government investment, is still small
- Niche product applications are typically coming out of small businesses that have a higher tolerance for risk
- Existing and emerging applications show promise:
  - CNTs for data cabling shielding and conductors in electrical power distribution
  - Metal oxides used in catalysts
- Nano-engineered materials:
  - Require consistent, repeatable processing, implementation and characterization which are not achievable today
  - Are limited by batch-processing until the input materials, and their incorporation into products, can be reliably controlled through scale-up

Focus Area Introduction: Review of Government Activities, cont.

Government then documented the following (assumed) industry needs to offset risk and increase the applications/benefit of Engineered Nanomaterials:

1. Evolution of Nano-scale Materials Processing/Scalability of Processing of Nanoengineered Materials
   - Nanomaterials are currently synthesized in small batches due to issues of reproducibility and uniformity of size – difficult to produce in larger scale production
2. Nano-Enabled Intermediate Products
   - Control of Nanomaterials-structure and properties during product manufacturing – ensure nano properties/structure is maintained throughout process
3. Nano-Enhanced Products/Nanomaterials and Products Design and Manufacture
   - Support transition of NNI's Nanotechnology Knowledge Infrastructure (NKI)
4. Workforce Health, Safety, Training and Development

Focus Area Introduction:
Review of Government Activities, cont.

Finally, Government queried industry through a Request For Information (RFI) to help provide insight as to:

- What are the products and applications that use Nanomaterials?
- What are the known gaps and risk to industry that limit the market potential of Nanomaterials and how could an institute focused on Nano-engineered materials could be a resource to industry to use to expand the market potential?
- What are the benefits to industry and government by establishing an institute?
- What role would an IMI play in providing these benefits?
- Is there evidence that an IMI would be sustainable?

An SME team was assembled to prepare specific questions and analyze industry response:

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- Focus Area Introduction: The State of Nanotechnology Today
- Review of Nanotechnology Processes/Ecosystem
  - Review of lifecycle of nano-engineered product from “root to fruit”
  - Analysis of technology gaps and industry risks at each stage
- Economic Impact of Advancement of Nanotechnology
- The Role/Opportunity for an Engineered Nanomaterials Institute
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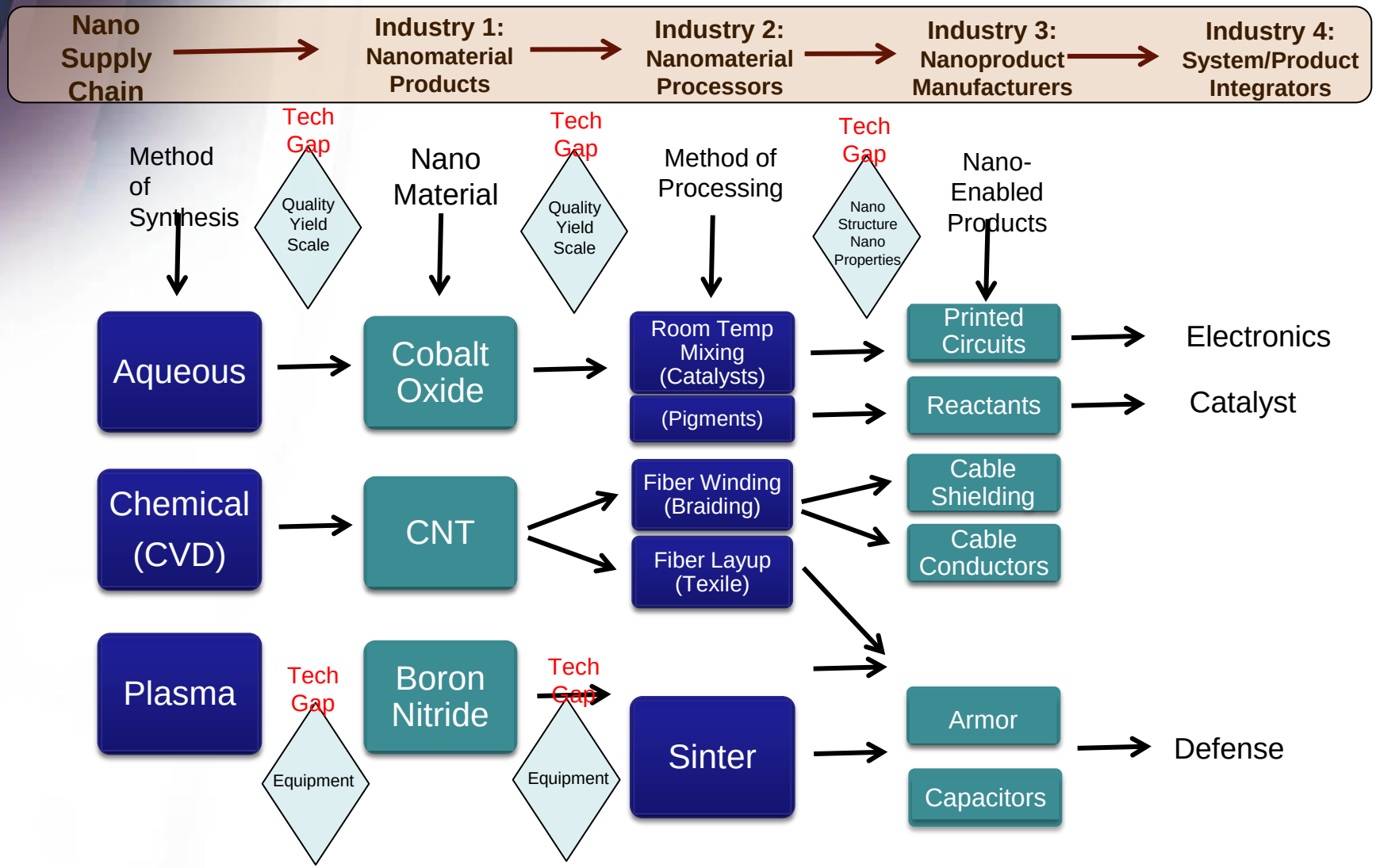
Engineered Nanomaterials Ecosystem



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Economic Impact: Technology Areas of Focus and Market Potential

1. Nano-additives, Nano-reactives, and Nano-structural materials
   - *Materials:* Boron Nitride/Carbide, Graphene, Ethylene/Propylene Oxide
   - *Applications:* Coatings, catalyts, adhesives, energetics, countermeasure flares, armor
   - *Market Potential:* $2.3B revenue by 2017, 17% CAGR
2. Nano-electronics:
   - *Materials: CNTs, Graphene, Ceramic Oxides*
   - *Applications:* Low-cost photovoltaics, advanced lightweight batteries, luminescent materials for solid state lighting, solar cells, power electronics, superconductivity, batteries, LEDs
   - *Market Potential:* $1.4B revenue by 2017, >= 25% CAGR
3. Nano-pharmaceuticals:
   - *Materials: CNTs, Graphene*
   - *Applications:* Nano-therapeudics, MRI contrast agents, Biomarkers
   - *Market Potential:* $540M revenue by 2017, >= 7% CAGR

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  - Discussion of institute requirements: market pull, matching funds, self-sustainment, etc.
  - Analysis of institute activities, capabilities and competencies) that are beyond the risk of industry
- Moderated Discussion Topics

Engineered Nanomaterials Institute: Gaps Identified

- Lack of scalable, low-cost manufacturing processes with high throughput/yield
  - Need to move from grams to kilograms
- Lack of process tools with in-line diagnostics
  - Lack of ability to control/maintain nanostructure
  - Limits diversity of applications and industries
- Capital investment/Financial risk
  - Significant and “unbound” investment required for nanomanufacturing due to lack of scalable, reliable and repeatable processes
- Environmental, Health, Safety, Occupational concerns
- Workforce development needs to focus on basic engineering vs. basic science

Engineered Nanomaterials Institute: Needs Identified

- An Engineered Nanomaterials IMI can leverage the significant investment made by NNI and other initiatives to complete development cycle and fill the gap between lab- and production-scale:
  - Address known technology challenges in manufacturing to shift from batch to continuous processing
  - Improve Nanomaterial quality/yield and remove impediments common to commercialization and scale-up
  - Act as a clearinghouse for the catalog of Nanomaterials
  - Create a central hub where costly characterization, synthesis tools and equipment can be shared
- An IMI should have competencies (knowledge) and capabilities (physical assets) sufficient to serve its members and the DoD

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